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The Influence of Knowledge Diffusion on Aeronautics Innovation: The Research, Development, and Production of Large Commercial Aircraft in France, Germany, and the United Kingdom.

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THE INFLUENCE OF KNOWLEDGE DIFFUSION ON AERONAUTICS INNOVATION: THE RESEARCH, DEVELOPMENT, AND PRODUCTION OF LARGE COMMERCIAL AIRCRAFT IN FRANCE, GERMANY, AND THE UNITED KINGDOM

by

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ABSTRACT

This paper focuses on how European public policies—individually and collectively—influence the diffusion of knowledge and technology. It begins with an overview of the roles played historically and currently by European governments in the research, development, and production (RD&P) of large commercial aircraft (LCA). The analytical framework brings together literature from global political economy, comparative politics, business management, and science and technology policy studies. It distinguishes between the production of knowledge, on the one hand, and the dissemination of knowledge, on the other. France, Germany, and the United Kingdom serve as the analytical cases. The paper concludes with a call for additional research in this area, some tentative lessons learned, and a discussion of the consequences of national strategies and policies for the diffusion of knowledge and technology in an era of globalization.

INTRODUCTION

Aviation has long had a close, often symbiotic relationship with the state. Decades of direct and indirect government support for the industry have produced an unprecedented level of sophistication in both military and commercial aviation. Governments have utilized a variety of market intervention instruments to promote the diffusion—production, transfer, and use—of aeronautical knowledge and technology. Individual European states—namely France, Germany, and the United Kingdom (U.K.)—have impressive histories of aeronautical innovation; collectively they—namely France, Germany, and the U.K., together with the Netherlands, Belgium, and Spain—have collaborated successfully since World War II to rebuild their indigenous aeronautical capacities under the Airbus Industrie (AI) umbrella. European collaboration to research, develop, and produce (RD&P) large commercial aircraft (LCA) is all the more remarkable because they do *not* share a common language or culture, but *do* share an extended history of mistrust and conflict. Add these obstacles to the incredibly complex task of LCA RD&P, and the enormity of their success becomes all the more impressive. This paper focuses on the innovation strategies and policies of France, Germany, and the U.K.; eventually, the analysis will be expanded to include knowledge diffusion strategies and policies adopted by the European Union (EU) as well. The intent is to learn which knowledge diffusion strategies and policies are efficient, effective, and successful in generating advances in goods and services nationally in a global economy characterized by mutual dependencies across a myriad of issue areas.

The diffusion of *aeronautical* knowledge and technology is particularly relevant to this task. *First*, both knowledge and technology are essential ingredients of the innovation required to create new or improve extant processes, products, systems, or services which are qualitatively superior or significantly less expensive than those already in the market. Innovation, in turn, is deemed critical both to national defense and to maintaining economic competitiveness in the global economy. In the realm of national defense, aviation is a keystone of the industrial base which produces the multitude of systems—weapons, transportation, communications, and infrastructure—as well as the personnel and training necessary to provide security. Aviation also serves as an economic linchpin, highly valued for its "spill-over" effects, either as a powerful force pushing innovation through a cascade of "down-stream" activities, or as a "first user" of novel technologies. The drive to attain and sustain military superiority and economic competitiveness has consistently compelled national governments to support science and technology pre-commercial research and development (R&D) (Cohen, 1994; Council on Competitiveness, 1994; Dertouzos, Lester, and Solow, 1989; Julius, 1990; Lopez and Yager, 1987; National Academy of Engineering, 1988;

Nau, 1974; Rapkin and Strand, 1995; Ruggie, 1975; Servan-Schreiber, 1968; Strange, 1988; Tyson, 1988; 1992; VanTulder and Junne, 1988; Williams, 1984; Yoffie, 1993).

Thus, aviation plays a special role in the national innovation systems of several of the most important countries in the Organization for Economic Cooperation and Development (OECD). In addition, for the United States (U.S.), the U.K., and France, aerospace products constitute a major source of manufacturing exports, adding a trade dimension to the strategic importance of that sector (Council on Competitiveness, 1996; Gellman Research Associates, 1992; 1990; Hayward, 1994; Nelson, 1993; Tyson, 1988; 1992; U.S. International Trade Commission, 1993; 1984; U.S. Congress, Office of Technology Assessment, 1991). Governments can use a number of strategies and policies to promote an industry sector, a particular project, or even a specific technology, including financial subsidies, information dissemination, government mandated technology transfer from foreign sources, technical standards, and government procurement (Pinelli, Kennedy, Barclay and Bishop, 1997, p. 135; Mowery, 1994). More broadly, public policy establishes the market parameters (e.g., trade and investment rules) as well as the education and legal (e.g., intellectual property rights) infrastructures within which innovation occurs.

Second, governments and corporations confront an intriguing problem with respect to the diffusion of knowledge and technology: neither has intrinsic value. Their value lies in their usability; that is, knowledge and technology must be accessible by the institutions, firms, or individuals which create or improve military or commercial processes, products, systems, or services. In addition, knowledge and technology must be "practical"—relevant and applicable to the goals of producing new or improved processes, products, systems, or services. Useable knowledge and technology are embedded with explicit (science) and tacit (engineering) components; they provide workable and effective solutions to problems. Generally, technological knowledge is best utilized by engineers because they have gained the *tacit* knowledge—personal, context-specific, experiential (see Pinelli, Kennedy, Barclay and Bishop, 1997, p. 90; Polanyi, 1966; Bateson, 1973; and Teece, 1981)—which enables them to deploy knowledge and technology most effectively. At a minimum, experienced employees who have worked with related materials, processes, and products will benefit the most from emerging technological knowledge; the tacit knowledge they have gained as a result of "learning-by-doing" and "learning-by-using" is invaluable as they attempt to innovate using new technologies.

Third, LCA RD&P and technological innovation share key characteristics: Each is inherently risky and requires grappling with unknowns that may be technical, economic, or merely the manifestation of personal and social variables (Rogers, 1982). LCA producers and technological innovators seldom work in a predictable environment; usually the payoffs are uncertain and distant. In the LCA sector, these imponderables comprise both "known unknowns" and "unknown unknowns"—referred to as "unk-unks."

> Known unknowns are the normal, unremarkable improvements that, it is assumed, will be called for sooner or later.... Unk-unks are the less predictable contingencies; the assumption is that any new airplane or engine intended to advance the state of the art will harbor its own surprises in the form of problems that are wholly unforeseen (Newhouse, 1982, p. 19).

Despite this remarkable level of uncertainty, LCA producers and technological innovators must make decisions and complete extraordinarily complex tasks. To do so they seek data, information, or knowledge

which will help moderate uncertainty. Hence, examples of successful (or even failed) knowledge management—such as we find in the European aeronautics experience—can provide important lessons for policymakers around the world.

Fourth, LCA RD&P is a knowledge-dependent industry sector the benefits of which—both tangible and intangible—are so clearly perceived by government policymakers around the world that virtually every nation will do what it can to participate in the sector. The question is what kind of intervention is efficient, effective, and successful.

BACKGROUND

Governmental officials are expected to adopt strategies and policies which they determine will enable their individual countries to be safe from external attack and to be economically viable. In a world where knowledge and technology are increasingly recognized as critical to the achievement of both military security and economic competitiveness, policymakers should explore how best to foster the most effective creation and dissemination of knowledge and technology for and to domestic users. If we define effective creation and dissemination of knowledge and technology as including the production of an economically competitive product, then, as we enter the twenty-first century, this task is complicated by the skyrocketing cost and collateral risk of this laudable goal. In an industry sector such as commercial aviation, the task is further complicated by the simultaneous expansion of the market to global proportions and the shrinking number of consumers. Add to this the problem created by the extraordinary cost of LCA to consumers, and policymakers are confronted with an almost paralyzing dilemma. Can they really expect to support and foster independent indigenous economic competitors without alienating foreign consumers upon whom they are dependent and with whom they are competing for sales? If not, how do they join forces with their competitors so as to enjoy the benefits of profitable production without undermining the success and survival of their indigenous capabilities?

European policymakers grapple with just this dilemma today. On the one hand, market forces seem to be compelling them toward greater unity and merging of capabilities; on the other hand, historical and political forces encourage protection from the vulnerability which inevitably accompanies the mutual dependencies of integration. The seedlings of this dilemma were first evident immediately following World War II as government officials and corporate decision-makers recognized the potential negative consequences of parochial state involvement for their own domestic economies in a world shrunk by increasingly sophisticated communications and transportation systems. The original intervention dilemma confronting state policymakers—finding the balance between excessive and insufficient government support of domestic economies—became one of how "to engineer a competitive presence in a full range of industrial activities with instruments of public intervention that are not necessarily very effective and that threaten the well-being of the international economic system" (Shepherd, Duchene, and Saunders, 1983, p. 21). The need to resolve this dilemma is exacerbated in industry sectors such as transportation and communication which are natural monopolies if private actors are allowed to act "freely" in the market (Chandler and Daems, 1980). As the market transitions from domestic to global proportions government and corporate officials must negotiate a compromise between unilateral and multilateral costs and benefits (Golich, 1992; 1991; Hayward 1994; 1986; Stirk and Willis, 1991).

Analytical Considerations

Four factors help us understand European approaches to knowledge and technology diffusion: *First*, nations can employ a "mission-oriented" strategy, a "diffusion-oriented" strategy, or some combination thereof (Ergas, 1987). The former is characterized by large scale project work, centering on large firms with a heavy emphasis on defense, nuclear power, and aerospace. The latter emphasizes broader, more generalized forms of investment, notably in pre-competitive, collaborative research, standards development, and training. "Mission-oriented" strategies are characteristic of the U.S., the U.K. and France where, since 1945, national defense and prestige have been key national goals. In contrast, Germany adopted a "diffusion-oriented" strategy; Japan adopted a unique hybrid approach (see Pinelli, Kennedy, Barclay, and Bishop, 1997). The general trend in innovation policy since the mid-1980s, when Ergas introduced the "mission" and "diffusion" distinction, has been to emphasize diffusionist strategies. To some extent, this trend follows the end of the Cold War which triggered a shift of resources away from defense programs to a growing preoccupation with economic competitiveness in a global market (Sandholz, 1992; Peterson, 1993).

Because aviation frequently involves or requires the building of prototypes, the development of proof-of-concepts, and flight tests (whether civil or military), it stands to benefit from mission-oriented governmental support perhaps more than other knowledge intensive, high technology industry sectors. The largest slice of aeronautical R&D is the "D" phase of getting something to work to specification. However, since the 1930s, development has been predicated on increased understanding of fundamental aerodynamics (i.e., theoretical and experimental) and the technologies associated with the RD&P of LCA. Such understanding requires, at a minimum, significant investment in an education system capable of graduating an appropriately trained workforce, including scientists, engineers, and highly skilled production workers; research, testing, and production facilities; and both fundamental and applied research, which itself may be best facilitated by the production of "technology demonstrators" to validate basic concepts and better aid the transition from design to production (European Union, 1992; Rosenberg, 1982).

Second, government intervention in the market varies across at least two dimensions: the level of intensity—or degree of involvement and direction proffered by the government—and preferred style—or degree of intervention transparency. Policymakers may actively guide and shape their national markets by creating consumer demand and by encouraging commodity supply. Alternatively, policymakers may prefer, rhetorically at least, to remain at arms length and intervene only when it is perceived to be absolutely critical. In addition, governments can employ a wide range of direct and indirect mechanisms as they seek to influence both supply and demand, including overt funding of R&D, production and sale subsidies, regulatory relief, tax incentives, enhanced intellectual property rights, technical assistance, expedited approvals for new products, antitrust rules, and so forth. The consequences of each of these policies, as well as many others, have been studied extensively by others. (For more on science and technology policy choices and consequences, see Alic, 1986; Chiang, 1993; Cordes, 1988; Ergas, 1987; Golich, 1992; Heaton, 1989; Logsdon, 1986; Mansfield, 1986; Mowery and Rosenberg, 1989a; 1989b; Nelson, 1984; Pavitt and Walker, 1976; Rothwell, 1982; Schacht, 1996). Most European states intervene more aggressively, more frequently, and with a set of policies that are more transparent than those used by the U.S. (For more on intervention instruments generally employed by European countries to influence market dynamics, see Gayle and Goodrich, 1990; Nelson, 1984; Shepherd, Duchene, and Saunders, 1983; Vernon, 1976).

Third, national and regional histories help explain why governments adopt distinct approaches to the production, transfer, and use of knowledge. The United States evolved into a "regulatory state" (Johnson, 1982), which, for the most part, focuses on implementing rules to guide market activity and eschews the establishment of economic targets as a government responsibility. Most modern European states emerged as political units during the era of economic mercantilism, when wealth and power were each considered proper ultimate ends of national policy (Golich, 1992; Viner, 1958). The early feudal political structures common to almost all antecedents of today's European nations obligated the governing elites to intervene in local economies. The classical liberal economics which replaced mercantilism in the late eighteenth and early nineteenth centuries still articulated a clear governmental responsibility for providing key infrastructures to facilitate trade (Kindleberger, 1978; Smith, 1958). As a result, firms in strategic industries—typically those related to transportation and communication—were frequently state-owned or were allowed to monopolize production and sales; despite the recent trend toward privatizing these firms and exposing them to greater competition globally, European governments—individually and collectively—remain quite willing to intervene openly and assertively to achieve economic or social goals. Insofar as the overall goal of European states is economic growth or social welfare, they can be considered "developmental" (Johnson, 1982).

European governments have adopted two broad categories of technology strategies and policies: general and selective subsidies (Fölster, 1991; Rothwell and Zegveld, 1981). General subsidies are used to promote the R&D activities of any firm, whereas selective subsidies target specific projects (e.g., the creation and maintenance of Airbus Industrie). European governments have chosen to employ an array of technology strategies and policies to encourage innovation for five reasons: (a) to overcome the disincentive to invest in R&D which derives from the fact that firms are seldom able to appropriate the benefits associated with the knowledge and technology they produce; almost by definition, knowledge and technological innovation is difficult to contain; (b) to spread risk more widely—across society as a whole—since firms may be too risk averse to engage in projects that are costly and have uncertain payoffs, hence government has an *obligation* to assume some or all of the risk; (c) to accelerate the diffusion of knowledge and technology among firms because to do so will encourage the adoption of profitable new product and process technologies deemed vital to firm-, industry-, and, ultimately, national-level competitiveness; (d) to increase returns to scale in R&D by increasing firm size; and (e) to discourage competitive and duplicative R&D at the firm level. (For a more detailed discussion of these points see Fölster, 1992, pp. 26-30. For more on levels of competitiveness, see Eden and Molot, 1996; Golich, 1996; Kudrle, 1996; Moore, 1996; Rapkin and Strand, 1996. For more on the effect of history, ideology, and culture on national approaches to innovation policy see Brander, 1987; Cerny, 1980; Chandler, 1977; Chandler and Daems, 1980; Chapman, 1991; Chesnais, 1993; Gillispie, 1980; Gilpin 1968; Golich, 1992; Hoffman, *et al.*, 1963; Keck, 1993; Markovits, 1986; Porter, 1990; Sorge, 1991; Talalay, Farrands, and Tooze, 1997; Underhill, 1997).

Fourth, policy choices are influenced by the perceptions decision makers hold with respect to their state's position in the international system (Golich, 1992; Haggard and Simmons, 1987; Ikenberry, 1986; Katzenstein, 1985; Servan-Schreiber, 1968). Whereas the United States was motivated in the 1980s to explore the use of policies to promote technological innovation due to a perceived crisis of competitiveness (Golich, 1996; Kudrle, 1996; Heaton, 1989; Porter, 1990), Europeans grew concerned with their economic competitiveness status as early as the 1960s (see, e.g., Organization for Economic Cooperation and Development, 1968; Scherer, 1992; Servan-Schreiber, 1968). Nevertheless, the publication of the "technology

gap" series of studies commissioned by the OECD (1968) and Servan-Schreiber's *The American Challenge* (1968) triggered an even more aggressive use of industrial and technology policies designed to sustain or reinvigorate their competitiveness vis-à-vis the U.S. (Scherer, 1992). Since 1945, the U.S. has been a world leader in aeronautics and, as such, has provided the competitive focus for European nations. Moreover, the U.S. remains the single most important market for many European and Asian companies—a fact that conditions many corporate and national technology strategies. Europeans, concerned that they were "becoming an economic colony of the United States" (Thornton, 1995, p. 19), recognized "that a broad capability in high-technology was more than a necessary requisite to military power; it had become essential to status as a first-rate economic power" (Hochmuth, 1974, p. 145). Aerospace was a logical focus for technology policy because its "strategic position extends beyond the obvious military significance of such industries to overall considerations of international status and predominance in the *future development of science and technology*" (Todd and Simpson, 1985, p. 33; emphasis added).

U.S. aeronautical leadership was obtained by close cooperation between state and industry. Extensive federal support for production, transfer, and use of aeronautical knowledge and technology began in 1917 under the auspices of the National Advisory Committee for Aeronautics (NACA). It was later strongly influenced by extensive Cold War military procurement and defense-related R&D, and managed by the NACA's 1958 replacement, the National Aeronautics and Space Administration (NASA). In short, this was a "mission-oriented" technology strategy *par excellence*; it worked largely due to the range, scale, and overlap of early U.S. civil and military "missions," and to the flexibility of U.S. organizational structures (Ergas, 1987). Europeans have consistently sought to remain competitive with the U.S. in key industrial sectors. In the case of aviation, three factors motivated their involvement: *First*, as in the U.S., it is strategic to both the national defense and the economy; *second*, by the end of the 1930s, they had yielded their position as a world leader in aeronautics to the U.S.; and *third*, they consider the downstream and lateral flows of technological discoveries into the broader economy as well as the upstream technological developments critical to LCA RD&P, as important elements in maintaining healthy employment.

What follows is an overview of the roles played by France, Germany, and the U.K. in promoting the production, transfer, and use of aeronautical knowledge and technology relevant to the RD&P of LCA. These three countries have been selected because of their critical position in the RD&P LCA historically and of Airbus Industrie aircraft currently. (It is important to note that the many countries which comprise the European continent differ significantly in histories, ideologies, cultures, traditions, governance structures, and policy selection and implementation patterns. For discussions of other European national approaches see, for example, Chiang, 1993; Guile and Brooks, 1987; Hart, 1992; Hayward, 1986; Hochmuth, 1974; Nelson, 1993; 1984; Vernon, 1970).

European Approaches to Knowledge and Technology Diffusion

Like many high-cost, knowledge-intensive industries, aeronautics—and especially LCA production—have looked outside of a purely national base for capital and technology. With aeronautics heavily dependent on the flow of "upstream" technological innovation—especially in materials, electronics, and process technologies—the industry adopted a transnational approach to technology scanning and acquisition (Rosenberg, 1982). Unable to match the U.S. in market size and R&D base, individual European firms and

their government sponsors were forced by budgetary pressure to cooperate in LCA RD&P since the mid-1960s. As a result, European product development in several areas—LCA, advanced combat aircraft, and satellite launchers—is now based on long-lived transnational consortia. With the exception of strategic missile systems, European collaboration has embraced every civil and military industry sector. Formal cross-border collaboration is underpinned by a global network of suppliers and subcontractors feeding components, equipment, and substructures into the prime contractors in the U.S. and Europe. The recent collapse in demand for military products, triggered by the fall of the Soviet Union, has combined with other commercial pressures to encourage the development of genuine transnational firms (Hayward, 1994).

The internationalization of aeronautics has created a set of intriguing problems for national innovation and trade policies due to the complex interpenetration of national aeronautical industry and technology systems. On the one hand, economic pressures and the globalization of knowledge and technology combined with the demands of foreign governments demanding partnership agreements as a price for market access to generate centripetal forces in the industry (Golich, 1992). On the other, governments and firms continue to prize technological leadership and the strategic importance of commanding "first place" in aeronautical innovation. This is not always a crudely nationalistic phenomenon: the position of European states is especially complicated, where corporate managers have acquiesced to the reality that European industry competes against the U.S. in core areas, but where a national edge is still valued as a means to influence the structure of joint ventures and to maximize individual returns from a collective effort. As a result, Europe's march toward collaborative RD&P has not been easy (Lorell, 1980; Stirk and Willis, 1991). As Nelson (1993) observes generally about global trends in technology policy, "there is a tension caused by the attempts of national governments to form and implement national technology policies in a world where business and technology are increasingly transnational" (p.18). Arguably, these tensions are especially evident in aeronautics where national strategies have to co-exist with, if not globalization, certainly with the regionalization of industrial and technological capabilities.

France, Germany and the U.K. together account for over 85% of Europe's total aerospace output. Of the three, France has the largest annual sales followed by Britain and Germany. The Spanish, Italian, Dutch—now almost entirely absorbed by Daimler-Benz Aerospace (formerly *Deutsche Aerospace A.G.*)—and the Swedish industries make up the remainder. Only the British and the French can claim a full scope of aerospace capability, with world class airframe, engine, and equipment companies in both the civil and military sectors. The British boast superior capability in civil engines, whereas the French and Germans have better space competence. Throughout Europe, states and firms share a long tradition of partnership in aeronautical civil and military development (Hayward, 1994). Governments have involved themselves directly in restructuring questions and, occasionally, in management through public ownership of major firms. What follows is an examination of this relationship: the role government has played in the aeronautical research and technology (R&T) in France, Germany, and the United Kingdom.

FRANCE

France has one of the most explicit and aggressive sets of national strategies and policies for aeronautics and space development in Europe. These strategies and policies have been in place since the late 1940s, but were given emphasis and direction by President Charles de Gaulle and have since been

reinforced by governments of both the Left and Right. The approach reflects a clearly articulated policy of national independence in arms production and of a modernized French economy based on developing high-technology industries (Gilpin, 1968; Kolodziej, 1987); it is grounded on the principle of *dirigisme*—a concept of guided industrial and technological development implemented through a mix of instruments including central planning (much less important now than in the 1950s and 1960s), state-funded research centers, public procurement, project subsidization, and enterprise capitalization. These technologies *à point* and their associated industrial structures comprise several

> strongly compartmentalized *sectoral subsystems* often working for public markets and invariably involving an *alliance* between the State and public and/or private business enterprises belonging to the *oligopolistic* core of French industry. (Chesnais, 1993, p.192)

Evolution of French Technology Strategies and Policies

The development of science and technology—not to mention a manufacturing base—in France has long been associated with public policy. Colbert founded the *Académie Royale des Sciences* in 1676 to foster scientific capabilities; members of the *Académie* explicitly linked science and technology to manufacturing. Public policy—in the name of Louis XIV—created the manufactures (Chesnais, 1993; Crossland, 1975; Gillipsie, 1980). This connection was reinforced years later during the Napoleonic Wars when the British naval blockade compelled the French to place science-based innovation in the industrial core. The pervasive role of the government in promoting targeted innovations has resulted in a corporatist arrangement—a triumvirate of government, business, and labor. As a result, French private capital only reluctantly supports entrepreneurship or innovation; such assistance is perceived as the responsibility of government.

Napoléon shaped French innovation policy by restructuring the system of higher education which trained scientists and engineers. After abolishing the university system of the *Ancien Régime*, Napoléon reinvented higher education by separating universities from "professional" or technical schools, known as *Grand Ecoles*. University students studied the more traditional and esoteric liberal arts. The *Grand Ecoles* focused on training *experts*, so students learned the results of science, but not the scientific method. Graduates took jobs as "production engineers who applied existing knowledge, rather than research engineers who could make substantial advances in the state of the art" (Chesnais, 1993, p. 197). Higher education was mobilized to serve military and industrial purposes, and France, home to three of the world's leading scientific institutions—*Collège de France*, the *Ecole Polytechnique*, and the *Muséum d'Histoire Naturelle*—became an international leader in science and technology. However, higher education did not continue to receive the kind of support it needed to sustain this status during the Bourbon Restauration; "reforms" during the Third Republic weakened the system further. By the beginning of the twentieth century, the divorce of science from industry for commercial purposes was well established. France had virtually no industrial R&D laboratories similar in form and function to those proliferating in the United States and Germany. As a result, few "science-push" industries developed in France. (For more on the evolution of French science and technology, see Cerny, 1980; Chapman, 1987; Chesnais, 1993; Cohen, 1977; Gillipsie, 1980; Gilpin, 1968; Hoffman, *et al.*, 1963; Kindleberger, 1978; Kolodziej, 1987; Kuisel, 1981; Papon, 1978; Underhill, 1997; Zysman, 1978.)

By the end of World War II, France's industrial foundation was in disarray. Technologically backward, small in size, and decimated by the German occupation, the industrial base suffered also from its own conservative tendencies. As Stanley Hoffman (1963) notes, France was a "stalemate society," where stability and protection were preferred over growth and competition, a Malthusian fear for overproduction of material goods and of educated people reigned, and agrarian and religious interests dominated industrial needs. It was no wonder that French industry was fragmented and restrained. Following World War II, the Fourth Republic took immediate steps to reinvigorate industry in general, and science and technology in particular. In a conscious effort to regain a foothold in the industry, France operated Europe's largest F-86 and B-29 maintenance facility in Chateurault (Samuels, 1994, p. 203). Several agencies were created for the specific purpose of research and technology in a number of areas, including nuclear power, telecommunications, electronics, agriculture, and medicine. The most important of these was the *Office National d'Etudes et de Recherches Aérospatiales* (ONERA, the National Institute for Aerospace Research and Studies), created in 1946 with the mandate to undertake and sponsor both civil and military research.

Another key agency is the *Centre National de la Recherche Scientifique* (CNRS, National Center for Scientific Research). Originally created in 1939, the CNRS was reinvented in 1945 to establish laboratories and research facilities, to support university research (in part by seconding science faculty), and to subvene scientific publications, purchase equipment, and support colloquia on scientific subjects. The CNRS is expected to evaluate, conduct, or promote all research assisting the advancement of science; to assist in the authentication and application of research findings; to disseminate scientific information; to coordinate research development; and to promote national and international collaboration. With the entry of the Fifth Republic and Charles de Gaulle, greater emphasis was placed on the use of National Champions to regain and maintain a competitive foothold in the global economy and to achieve independence in national defense. In many ways, though some effort was made to move certain industrial sectors into the private sphere, the government remained as involved, if not more, than before (Cerny, 1980; Gilpin, 1968).

French Public Policies Affecting the Diffusion of Knowledge and Technology

Today, French strategies and policies affecting the diffusion of knowledge and technology feature four key characteristics. *First*, the extent of government involvement in R&D and technological innovation is significant. More than 50% of the funds expended for R&D are provided by the government. The bulk of these funds target the aeronautics, electronics, nuclear energy, space, and telecommunications industries. However, many of the programs and projects undertaken in France are designed and dictated by government officials and bureaucrats. Government involvement in such undertakings tends to pull decision-making away from program and project managers, create a rigid hierarchy, foster competition rather than cooperation, and lead to antagonistic relationships between labor and management. As a result, government involvement in technological innovation has produced mixed results. Only two industries—pharmaceuticals and aviation—can boast that they contribute positively to the nation's overall balance of trade. (For more on the structure of R&D, technological innovation, and the diffusion of knowledge and technology in France, see Cerny, 1980; Chandler and Daems, 1980; Chesnais, 1993; Hoffman, *et al.*, 1963; Underhill, 1997).

Second, since 1945, French technology strategies and policies have been heavily influenced by a strong linkage to the military, with little concern for generating dual-use technologies. The Ministry of

Defense, through its *Delegation General pour l'Armement* (DGA, the Defense Procurement Office) oversees 35% of all French public R&D. It has responsibility (or *tutelage*) for the space industry's technical and commercial development, whereas the Ministry of Transport oversees civil aviation programs and airlines only. The Defense Ministry also has authority over ONERA, which is responsible for about 12% of French aeronautical research with two-thirds of its funding derived from government contracts. ONERA is an interdisciplinary research institute where scientists and engineers work with technicians and highly skilled workers to advance theoretical, computational, and experimental knowledge. ONERA researchers have at their disposal all the scientific instruments, technical, and test facilities required both for long-term research and for development projects concerning fixed-wing aircraft, helicopters, missiles, launch vehicles, and spacecraft. When French firms contract with ONERA, the fee is dependent on the degree to which results are open to other companies; if they are generally available to industry, ONERA bears the bulk of the cost.

Unlike the U.S., where one agency—NASA—conducts R&T related to both aeronautics and space, the French have a separate agency—the *Centre National d'Etudes Spatiales* (CNES)—which performs space-related R&T (Hayward, 1994; Kolodziej, 1987; U.S. Congress, 1994a). Recently, French industrialists have called for more money to be spent on technology demonstrators and research programs similar to those conducted by NASA and the Advanced Research Projects Agency (ARPA, formerly the Defense Advanced Research Projects Agency, or DARPA). In making their case, they argue that maintaining a national commitment to defense R&D is vital not only for the future of French military aerospace but also for the general health of the French aircraft industry (Covault, 1993; Sparaco, 1993; Velocci, 1993).

Since the late 1970s, the French Ministry of Defense has actively sought greater dual-use synergies from its research. A new directorate, *Direction des Recherches, Etudes et Techniques* (DRET)—analogous to the U.S. (D)ARPA though lacking in its flexibility and responsiveness—was created in 1977. DRET has been charged with coordinating all defense-related work in the public and private sectors (including "dual-use" technologies), monitoring defense-related developments in S&T generally, and helping to define French defense research priorities (Adkins, 1993; Sparaco, 1994; U.S. Congress, 1982). DRET has 2000 staff and funds approximately 200 medium to long term projects annually, including some work at ONERA. Like most of their European neighbors, the French place no legal, regulatory, or accounting barriers to combining military and civil activities in the same facility. One of the more notable successes of this approach is the CATIA (Computer-Graphics-Aided Three Dimensional Interactive Application) Computer-Aided-Design/Computer-Aided-Manufacture (CAD/CAM) system, which was first developed by Dassault and IBM as part of the Mirage 5 fighter program and later used by Boeing in its RD&P of the prize-winning 777. British industrialists and policymakers envy the responsibility assumed by the Ministry of Defense for maintaining the health and vitality of France's defense industrial base. This is understandable given the neglect shown by Britain's Defense Ministry for doing the same in the U.K. (U.K. House of Commons, 1993).

Third, a unique feature of French technology strategies and policies is the concept of the *technopole* —regional centers of excellence developed to capitalize more widely on public investments in high technology programs. *Technopoles* were intended to create a "critical mass" of scientists and engineers for a certain technology and to stimulate associated knowledge, technology, and industrial development. Mature *technopoles* were act as a magnet for other high value, high technology industries which would derive advantage from access to an increasingly skilled workforce and a research-dense community. Toulouse, home of the

Ecole Supérieur de l'Aéronautique et de l'Espace (SupAero)—the premier aeronautical *Grand Ecole*—has been the main *technopole* for commercial aeronautics and space-related activities. After World War II, it became the main focus for civil aircraft programs, including the Caravelle, the Concorde, the Airbus, and the Franco-Italian ATR regional transport consortium.

Fourth, an interlocking network of industrial executives and government officials—virtually all alums of the *grand écoles*—manage the entire chain of production in France. At the highest level, this can lead to politically-driven changes in senior management of the state-run enterprises. More importantly, the consequence of this tightly knit network is that both sides have a close and detailed insight into the general direction of technology strategies and policies; as a result, the often rigid and conservative approaches to innovation in France are reinforced.

In addition to the abbreviated list of agencies noted previously, two deserve mention as recent additions to the French innovation system. The first is the *Agence nationale pour la valorisation de la recherche* (ANVAR, National Agency for the Promotion of Research). Funded by the French Ministries of Research and Education, this national agency for the promotion of research provides technology "diagnostics" tests to identify the market potential of products. It also conducts marketing studies and offers legal assistance. The second is the *Centres régionaux d'innovation et de transfert de technologies* (CRITTs). Created in 1982, this institution promotes joint and cooperative ventures between pubic and private organizations (Adkins. 1993; Chandler and Daems, 1980).

The Evolution of French Innovation Public Policy in Aviation

In many ways, the history of aviation in France is a testament to the conservative, risk-averse approach to entrepreneurship and innovation previously discussed. At the same time, however, aviation stands out as an incredible success story in at least two time periods: in its earlier years unfettered by government involvement *and* more recently as the government has shifted from a mission-oriented to a diffusion-oriented set of strategies and policies, at least in aeronautics.

In its early days, individual entrepreneurs and engineers combined their efforts to launch French aeronautics and aviation. Their accomplishments are legendary: Frenchmen flying French planes rivaled U.S. competitors for world records; Farman and Bréguet were net exporters of aircraft; Gnome and Rhone, Hispano, and Renault were net exporters of engines. Eventually, a combination of very slow economic growth and an ultraconservative French officer corps depressed demand and the fragmented structure of competitive firms hampered further development. Aircraft manufacturers confronted a major obstacle to their advancement: an entrenched pattern of government patronage in industry. French policymakers tried repeatedly to compel these engineer-entrepreneurs to merge into larger companies based on the *technopole* logic, but the manufacturers resisted. They preferred to cluster themselves into *groupements* instead. This configuration offered individual companies autonomy: within their *groupement* they could preserve their

> own fixed capital, production facilities, research laboratories, and administrative services. Each group created a central bureau to parcel out orders to member firms, negotiate contracts, and search for foreign clients. In effect the groups served more as marketing cartels.... (Chapman, 1991, p. 37).

This industrial structure fell far short of the genuine concentration desired by French policymakers, but did carry the firms closer to a unified structure.

Léon Blum's Popular Front nationalized commercial aircraft manufacturers in 1936. Several small firms merged to form larger *groupement* and two prominent engineer-entrepreneurs, Bréguet and Dassault, lost their factories. (This pattern followed the government-directed 1932 rationalization of French airlines into a single company with the French government as an important minority stockholder.) As a result of the German occupation during World War II, French aviation languished until after the war, when the industry was nationalized again, and government officials used low-cost credit, direct subsidy, import protection, government procurement, and investment financing to promote LCA RD&P. In addition, firms were "required to subcontract extensively with one another in order to utilize all production resources" (Hochmuth, 1974, p. 165). This, together with the *groupement* structure of industry already in place, helped set the stage for collaboration in Airbus Industrie.

Since the 1960s, the French government has encouraged the formation of several "national champions" in aeronautics: Aérospatiale in civil airframes, missiles, and helicopters; Dassault in fixed wing military aircraft and business jets; *Société Nationale d'Etude et de Construction de Moteurs d'Aviation* (SNECMA) in engines; and Thomson-CSF, Dassault Electronics, and Sextant Avionics (a grouping of Aérospatiale and Thomson) in avionics and equipment. All French aerospace firms are entitled to receive launch aid, production credits, or advanced reimbursables for civil programs; the French government also provides capital infusions and organizes financial restructuring when necessary. Aid is repayable from sales and has been up to 100% of costs; more recently, the level has been closer to 50% or less (U.S. Congress, 1991).

Eventually, France added international collaboration to its mix of industrial support. Several factors combined to impel the French to travel this path. The Algerian War drained the French treasury and LCA RD&P suffered from the loss of government financial support. Foreign sales and investment were needed and collaboration seemed an obvious way to generate both. Germany and the United States were beginning to dominate aeronautical R&D and the French wanted to tap into that technological expertise. Continental collaboration was viewed as a means of driving a wedge between the United States and the United Kingdom. Finally, the French feared its aeronautical firms would suffer from a rationalization process occurring in the industry at the global level which would relegate them forever to the status of component suppliers (Golich, 1991; Lorell, 1980).

Typically, the French seek leadership roles in international management consortia such as Airbus Industrie. In the case of the latter, the French heavily promoted Toulouse as the center for Airbus final assembly and commercial exploitation, and resisted strongly, though unsuccessfully, German demands for a final assembly of all new narrow-bodied transports. Most French collaboration has had a European focus; however, the French partnered with the United States' General Electric Aircraft Engine Group (GE) to build civil engines despite the "natural" link with the British firm, Rolls Royce (RR). France's SNECMA joined forces with GE to build the highly successful CFM-56 family of aircraft engines (Hayward, 1986; 1994). On projects such as Concorde, Airbus, and the CFM56 engine, French industry benefitted from working with equal or superior partners in the U.K. and the United States.

Currently, French technology strategies and policies can be characterized as a blend of mission and diffusion orientation. Informed by policymaker perceptions about France's global status—particularly *vis-à-vis* the United States, but also with respect to potential Continental competitors—and by historical precedent, French public policies have consistently and carefully (if not always successfully) promoted specific projects in strategic industry sectors. They have done so to achieve multiple goals. At the most obvious level, these policies have been designed to generate an original product—e.g., the Airbus Industrie aircraft. In addition, the French have quite openly sought to gain and maintain a leadership position in certain high technology industries because they recognize both the spill-over effects into downstream industries *and* the critical pull effect for upstream industries. Finally, the French have consciously aspired to satisfy social and economic welfare goals with their strategies and policies. In particular, they have sought to create and maintain high technology, high wage jobs. To achieve these ends, French public policy has employed transparent intervention tools, including education, urban planning, subsidy, ownership, and a variety of protections against foreign competitors. Judged simply by the leading role played by French companies in so many major European aerospace programs, France's national aviation and space-related technology strategies and policies would have to be considered a success. For example, in 1974, when the first Airbus aircraft was shipped, management's stated goal was to capture one-third of the LCA market; by 1995, after a shaky beginning and an uncertain period through the late 1970s, Airbus held roughly 30% of the market; a year later, Airbus' claim to market share had increased to nearly 33% (Aboulafia, 1997, p. 43; Proctor and Sparaco, 1997, p. 371).

GERMANY

Unlike France, Germany has pursued "diffusion-oriented" technology strategies and policies, with little emphasis on defense R&D relative to that given to commercial R&D (Becher and Ag, 1993; Keck, 1993). The German government has provided support for a research infrastructure and training since the late 1800s; post 1945 prohibitions reinforced these structural patterns. Since World War II, both the federal (*Bund*) and state (*Länder*) governments have funded programmatic research activity. At the federal level, governments from both the Left and Right have supported a series of high-cost projects including Airbus and space-related activities. *Länder* have complemented this assistance with their own promotion of technological innovation; for example, the Bavarian government has backed aerospace and automotive industrial development. Since the mid-1960s, Germany has pursued a well-conceived strategic approach to aerospace R&D encompassing its three main sectors—commercial, military, and space. The primary aims were to obtain the competitive and broader economic benefits perceived to be associated with aerospace, and to defray the costs of German defense commitments to the North Atlantic Treaty Organization (NATO). Regional interests were also served by supporting aerospace centers in the north and south of Germany (Hayward, 1990). More recently, German aerospace has struggled to absorb and to modernize the limited capabilities of the former *Deutsche Democratische Republik* (DDR, or German Democratic Republic).

Evolution of German Technology Strategies and Policies

Germany became a unified political unit rather late in the game. While France, the U.K., and the U.S. were consolidating national identity, Germany still consisted of individual territories, each complete with its own laws, currency, weights and measures, taxes, and custom tolls. Even after merging to form the German empire in 1871, the *Bund* exercised authority over very few functions, such as foreign policy and nation-

al defense. The formation of the German nation-state was influenced significantly by economic concerns. To enable German industry to catch up with the industrialized countries—particularly Britain and France—Friedrich List proposed a customs union which would protect "infant industries" from stronger competition (Keck, 1993; Tickner, 1987). From this beginning, Germany proceeded to acquire by virtually any means possible—espionage, immigration, procurement of machinery, and education—the knowledge, technology, and skilled workers needed to move from an agrarian to an industrial economy.

Germany successfully adopted the French university system of the early nineteenth century as a primary focus of scientific research. Supported by a network of institutes with laboratories for the natural sciences, as well as specialized libraries for the humanities, university research quickly elevated Germany to world leadership in medicine, chemistry, and physics. However, little was done in the realm of engineering. Recognizing the value of skilled technicians to industrialization, the Prussians established a system of polytechnical schools, which stressed the use of the scientific method and mathematics, to train research engineers and engineering technicians. By 1870, these schools—called *Technische Hochschulen*—had ascended to a status nearly equivalent to universities. "By the beginning of the twentieth century Germany had established a sophisticated system for education in scientific, technical, and commercial matters, reaching from elementary school to the doctoral level" (Keck, 1993, p. 122). The system graduated more engineers, engineering technicians, and scientists—relative to the size of its population—than France, and attracted students from around the world.

In addition to federally-provided higher education, German *Länder* established 40 to 50 institutes for specialized research in a number of applied areas, including weather and atmosphere, geography and geology, shipbuilding, and hydro engineering. Building on that tradition, the *Bund* established the Imperial Institute of Physics and Technology (*Physikalisch-technische Reichsanstalt*) in 1887, to work on standards and measures for the development of precision instruments, a pattern that was replicated across many of the science disciplines. Yet another mechanism to finance fundamental and applied R&T was based on the U.S. model of tapping industry for research funds: The Kaiser-Wilhelm-Society (precursor to the Max-Planck-Society created in 1948) used resources from industry and governments—including real estate, salaries, and subsidies—to finance both basic and applied research in chemistry, physical chemistry, coal research, biology, and experimental therapy (Keck, 1993).

By the beginning of the twentieth century, Germany was the envy of many other industrialized and industrializing states. Taking advantage of its position as a technology follower, Germany adopted new technology from abroad and moved it to useful production efficiently and effectively. Though seriously disrupted by World Wars I and II, Germany had created an impressive system of knowledge diffusion—a variety of higher education opportunities coupled with multiple research venues—which enabled its firms and industries to create new or improve existing processes, products, systems, and services as advances in science and technology became available. (For more on the structure of R&D and technological innovation, and the diffusion of knowledge and technology in Germany, see Allen, 1987; Becher and Ag, 1993; Hart, 1986b; Kuster, 1974; Meyer-Krahmer, 1990; 1992; Schimank, 1988; v. Massow, 1983; Warnken and Ronning, 1990; Wortmann, 1990).

German Public Policy Affecting the Diffusion of Knowledge and Technology

The diffusion of knowledge and technology in Germany today—still decentralized among industry, the *Bund*, and the *Länder*—is part of a broader industrial policy which is embedded in a "general economic policy aimed at maintaining full employment with stable prices, balanced foreign trade and satisfactory expansion" (Organization for Economic Cooperation and Development, 1971, p. 27). Public policy focuses on maintaining a system of higher education and facilities, as well as engineers and scientists, who can conduct the basic research necessary for technological innovation. The system benefits from the public provision of a research infrastructure, including data networks, university chairs for computer science, hospital research groups, and genetic research centers. Financial subsidies are limited to social needs (environment, health, and climate), to key sectors of national or European technological and economic competitiveness, and to long-term development of scientific and technical knowledge and technology (Schmidt-Küntzel, 1993). Tax incentives have also been employed to encourage appropriate industry-level R&D.

The Bundesministerium für Forschung und Technologie (BMFT, or Federal Ministry for Research and Technology)—the primary source of R&D funds in Germany—does not subsidize individual firms through direct project financing. Instead, it finances specific technology developments, with support not exceeding 50% of development costs. The BMFT fosters the diffusion of knowledge and technology among German universities, research institutes, and industry, and links technology-oriented enterprises and research establishments by (a) sponsoring internships in R&D institutions for young industry scientists and engineers to help develop their skills and their (tacit and explicit) knowledge base; (b) partially funding R&D contracts to small and medium firms; (c) providing incentives for collaborative research in contracts to universities, R&D institutes, and industry; (d) helping firms pool pre-competitive data, information, and knowledge; (e) creating links and alliances between suppliers and users of specialized inputs; (e) fostering inter-firm communications about knowledge and technology that exist outside their companies; and (f) establishing centers of excellence to serve as "honest brokers" and provide neutral and independent data, information, and knowledge to industry in an effort to reduce the uncertainty and risks associated to the introduction of new technologies. Occasionally, BMFT offers "indirect-specific" incentives to speed up the diffusion of knowledge and technology transfer to particular industry sectors (Bruder, 1983; Humphreys, 1989; Keck, 1993; Kreile, 1978; Meyer-Krahmer, Gielow, and Kuntze, 1983; Meyer-Krahmer, 1981; Schmidt-Küntzel, 1993).

Schmidt-Küntzel (1993) outlines the current German diffusion infrastructure: *First*, universities and their research institutes (primarily supported by *Länder*), the Max-Planck-*Gesellschaft* (MPG), and the *Deutsche Forschungsgemeinschaft* (DFG, German Research Association) (jointly financed by the *Bund* and *Länder*) conduct most of Germany's basic research. Largely autonomous, they have established a solid reputation for German science. *Second*, the National Research Centers (GFE) receive 90% of their support from the federal government and 10% from one or more host *Länder*. Originally created for nuclear research, they now work on applied energy R&T, particles research, as well as information, communications, production, and process technologies. *Third*, the *Fraunhofer Gesellschaft* (FhG, Fraunhofer Society), created in 1949, is financed by the BMFT and industry at a 60:30 ratio. FhG institutes actively work to diffuse knowledge and technology. With its links to universities and industry, the FhG helps reduce the gap that opened in the German innovation system when the Max-Planck-Society moved toward basic research. *Fourth*, multiple science foundations modeled on the order of the Rockefeller Foundation (e.g., the Volkswagen Founda-

tion), complement government efforts by providing seed money for new or unorthodox initiatives. *Fifth*, German industrial firms and organizations finance 86% of their own R&D.

The Evolution of German Innovation Public Policy in Aviation

In the early days of aviation, Germany (and Holland) challenged France for superiority. Germany partnered with Anthony Fokker—after the British and the Dutch governments rejected his aircraft sales offer—in an explicit effort to build up its military arsenal leading up to World War I (Lederer, 1985; Middleton, 1986; Weyl, 1965; Winter, Byshyn and Clark, 1969). Between wars, German aerodynamicists and engineers, prohibited by the Treaty of Versailles from building airplanes of more than 100 horsepower, turned to gliders to learn valuable lessons in aerodynamic structure that later benefitted German aircraft design (Winter, Byshyn, and Clark, 1969). Germany also continued its collaborative work with Fokker and established firms to work on aircraft in other countries. Thus, in 1925, when finally permitted to conduct passenger operation, Germany was the only country with new generation aircraft; other European nations had concentrated on converting military airplanes into commercial planes. Once the treaty restrictions were dropped, Germany's aviation industry became a thinly disguised military machine.

From 1945 to 1955 Germany's aircraft manufacturing sector virtually ceased to exist as new treaty requirements forbid "flying even model airplanes, much less gliders" (Winter, Byshyn, and Clark, 1969). When Germany re-entered the LCA production sector, it first tried to move from licensed co-production to indigenous programs. Explicit government support for commercial aviation began in 1962 and was separated from military R&D with the Ministry for the Economy exercising authority over the former, and the Ministry of Defense over the latter. Eventually, R&D costs and market size problems forced Germany to adopt international collaboration as a strategy to sustain indigenous production. This led to participation in each of the major European aircraft projects—including Airbus and the Tornado bomber—and significantly increased German industrial competence, especially in airframe and engine technology. Most of Germany's recent collaborative ventures have been with European partners, but since the early 1970s, the Germans have supported European links and alliances with the U.S. on space programs. The German aircraft industry is also working with Rockwell International on the NASA-funded X-31 demonstrator program.

Substantial weaknesses in German equipment and avionics capabilities remain, largely attributable to the lack of German-led programs and the dominance of British and French firms in the more technically advanced aspects of major collaborative programs. For example, in 1993 and 1994, when the Experimental Fighter Aircraft (EFA) development ran into problems, German inexperience with systems design and integration was blamed. Recently, German policymakers have taken a more aggressive line in demanding access to higher value design and more demanding industrial responsibilities. These ambitions were underlined by the formation of *Deutsche Aerospace A.G.* (DASA) as a subsidiary of Daimler-Benz, one Germany's most important manufacturing companies. Renamed Daimler-Benz Aerospace, DASA was created through multiple mergers of German aircraft and engine manufacturers and the acquisition of the outstanding shares of the Netherlands' Fokker Aircraft. This restructuring brings together under one roof the bulk of German airframe, missile, engine and avionics activity; the other main aerospace companies are Siemens in avionics and BMW in engines.

Government support for aerospace has been channeled through defense procurement, a growing space budget, and repayable launch aid for civil programs. Public funding is provided through the BMFT, the German research establishments, the *Deutsche Forschungsantalt für Luft- und Raumfahrt* (DLR) for aeronautics, and through research conducted by universities and other institutions. The German Ministry of Defense only funds research for specific military programs—a measure designed to prevent the distortion of research priorities by national security. The DLR is specifically remitted to support high risk, long term aeronautical R&D. Over half of its funding comes directly from the BMFT budget, with the remainder provided under industry or government contract (U.S. Congress, General Accounting Office, 1994).

Government financial support for German aerospace was hit by the downturn in defense spending—up to 60%—since 1990. In common with other major European aerospace states, German aerospace is dependent on large scale military programs such as EFA to generate many of the advanced technology concepts that underpin its overall capabilities. Budgetary priorities associated with reunification have also led to reductions in space and general aeronautics R&D budgets. Nevertheless, support for LCA RD&P has grown by 63% since 1981, with the bulk of the money going to Airbus Industrie. The German government has pledged to spend $738 million for civil aeronautical research between 1995 and 1998. The commitment was based an eight-point plan for the industry published in November 1993, which called for

- a multilateral GATT agreement;
- strict enforcement of the existing GATT agreements;
- creation of a new support structure for R&D;
- a separate aeronautical research program under the European Union Framework program;
- maintenance of minimum defense industrial capacities;
- support for satellite technology investment;
- retention of more air force overhaul work in Germany; and
- promotion of a wider public understanding of the importance of aerospace technology and its contribution to economic growth ("Facing the Crisis," 1994).

Although some doubts linger regarding German willingness to support expensive aerospace programs indefinitely, (given the continuing costs of unification), clearly both government and industry want to increase Germany's role in collaborative programs and its influence over the future of European aerospace. For example, German determination to increase its share of the Airbus program—especially to obtain final assembly responsibilities—has been fueled, in part, by its desire to reduce the industry's defense dependence.

Germany's diffusionist approach is firmly grounded in the assumption that targeted access to advances in knowledge and technology benefits the nation and its economy. The approach is reinforced by a history of direct government involvement both in the economy and in knowledge and technology diffusion. The success of this approach is perhaps best manifested by Germany's remarkable economic recovery following World War II. Even with the adjustment problems triggered by the reunification processes still under way, Germany's economy remains the keystone of the European Union. It has a well-deserved reputation for the meticulous RD&P of fine automobiles, electronics, and pharmaceuticals, and has made impressive advances along the steep learning curve of LCA RD&P. Its participation in Airbus Industrie signifies and supports continued advancement along this curve and generates important economic and social welfare benefits.

THE UNITED KINGDOM

Like France, the British government has played both direct and indirect roles in the industry's development, and its involvement has typically been characterized by a mission-oriented approach. However, in contrast to the more consistent approaches to innovation in France and Germany, British technology strategies and policies have vacillated in intensity and style, reflecting oscillations in its public policy generally that have accompanied changes in government. Though the resulting uncertainty and volatility have wreaked havoc at times in commercial aviation, the United Kingdom is still one of the world's leading aerospace countries, ranked second in Europe (behind France) in terms of sales. In addition to a major LCA engine firm—Rolls Royce—and a prime manufacturer of smaller regional aircraft—British Aerospace (Bae)—Britain is home to globally successful equipment and avionics industries. The U.K. spends much of its publicly-funded R&D on defense with a strong emphasis on aerospace. A separate research budget supports civil aeronautics, and a range of state-assisted research facilities—now consolidated in the semi-privatized Defense Research Agency (DRA)—fosters both civil and military R&D.

Evolution of British Technology Strategies and Policies

The evolution of any conscious technology strategies and policies in the U.K. is fairly short compared to other OECD states, and was precipitated largely by World Wars I and II and the Cold War. Until shaken by these traumatic events, early successes at achieving political stability—at least since 1688—and economic prosperity—as manifested by its longstanding position as the global economic hegemon and its "first mover" through the Industrial Revolution—provided little incentive to change. The British adopted political and economic liberalism sequentially—not simultaneously as in the United States (see Pinelli, Kennedy, Barclay, and Bishop, 1997, Chapter 2)—and avoided the violent upheavals which defeated feudalism in countries such as France or Germany. As a result, tradition and ritual associated with many "pre-capitalist elements of deference and truculence" embedded in such enduring cultural conventions as the monarchy and the aristocracy have proven remarkably resistant to change (Desai, 1989, p. 302). For example, the Industrial Revolution of the eighteenth century was launched by religious dissenters who were shoved out of university education and turned to pursue the "practical arts" of engineering and science in their own "public" schools; the landed, capital-rich aristocracy—educated in ancient languages and philosophies—played a relatively insignificant role. Still, to this day, the latter typically comprise the governing and corporate elite, whereas the workers and researchers critical to production and innovation come from the middle-classes. (For more on the historical development and continuing influence of Britain's culture, see Burke, 1986; Chandler and Daems, 1980; Desai, 1989; Gilpin, 1975; Hobsbawm, 1987; Sen, 1984; Walker, 1993; Wiener, 1981).

As a "first mover," Britain was not initially threatened by the industrialization efforts undertaken by its continental neighbors or colonial possessions. Its empire spanned the globe providing massive markets for the new goods produced; except for its role in acquiring and maintaining these territories, the state has been notably absent in the evolution of technological innovation. Until recently, the British government's economic role was primarily confined to some regulatory functions—e.g., financial markets and property law—and to the advancement and military protection of foreign trade. Unlike the governments of France and Japan, the British state has not acted as an entrepreneur itself. When it did take more aggressive and

transparent steps to influence the economy in general and commercial aviation in particular, the learning curve for effective intervention was painful and steep (Hayward, 1989; 1983; Walker, 1993).

Because early industrialization occurred despite governmental neglect and in the absence of any kind of technology-focused educational or innovation system, few policymakers presumed such an infrastructure was needed. Unfortunately, the culture and institutions that first sparked and then sustained industrial development in the late 1700s and early 1800s proved inadequate for the new industries that emerged in the late 1800s and later served to underpin economic advance throughout the twentieth century; for them, scientific understanding and methods informed—sometimes consciously and sometimes unconsciously—critically important technological advances. To make matters worse, the early successes seemed to breed eventual failure insofar as industrial and governmental leaders became obsessed with defending rather than expanding their markets and territories. At the same time, the power of organized labor increased as managerial authority and competence weakened. Ultimately, of course, the spread of industrialization to other states—which, as late comers, generally recognized more clearly the value of technological innovation—developed competitors and eventually undermined Britain's hegemonic position. Ironically, Britain aided and abetted the process by exporting its capital and technology and maintaining an open international trading system (Gilpin, 1975; Hobsbawm, 1987; Landes, 1969; Mackinder, 1904; Sen, 1984; Stein, 1984).

British Public Policies Affecting the Diffusion of Knowledge and Technology

The hallmarks of British public policies meant to influence the diffusion of knowledge and technology are instability, vacillation, and lack of coordination between state and market actors. These characteristics derive largely from "the violent doctrinal swings that have occurred in British governance," but also from belated "reactions, and often overreactions, to the perceived failure of policies during the preceding period" intended to arrest economic decline (Walker, 1993, p. 187). Four key factors have affected the development and implementation of technology strategies and policies, such as they are. *First*, like France and the United States, the U.K. has generally pursued a "mission orientation" to knowledge diffusion driven by perceived military needs. Defense procurement absorbs the largest portion of high technology engineering resources. The consequences for Britain have been largely negative. With a relatively weak technology skill base, the emphasis on military R&D has resulted in little spinoff into the civil sector. This is exacerbated by the fact that, even though there are few boundaries within individual firms with regard to transferring military technology to commercial projects, Britain's Ministry of Defence, unlike the Pentagon in the U.S. or the *Délégation Générale pour l'Armament* in France, resolutely refuses to take responsibility for the development of technologies that are not tied to specific defense needs (Kaldor, Sharp, and Walker, 1986; Kaldor, 1982; Advisory Council on Science and Technology, 1989; Walker, 1993). The specialized needs of the military begets what Kaldor (1982) calls "baroque technology" with little relevance to the commercial sector. And, finally, firms with technological capabilities are lured away from risky, market-oriented ventures—in the absence of public support—toward the guaranteed profits associated with military contracts.

Second, the educational infrastructure in Britain is not adequately designed to graduate highly skilled engineers and production workers as well scientists. A formal education system did not even exist in Britain until the late nineteenth century; as in France, university education focused on the more traditional and esoteric liberal arts. Since the 1960s, a number of reforms have been implemented, however, British

education remains elitist. Access is determined more by wealth and class status than by talent or ability; as a result, a smaller proportion of young people move into any kind of higher education. Britain possesses no equivalent of the French *Grand Ecoles* or *Polytechniques* or the German *Technische Hochschulen* to train engineers, scientists, technicians, and managers; consequently, the "output of skilled manpower is lower at all levels in Britain than in France and Germany" (Walker, 1993, p. 179; Prais, 1988).

Third, the British innovation "system" lacks effective coordination among the various players. Britain possesses few, if any, "bridging" institutions similar to Germany's *Fraunhofer Gesellschaft*; scant producer-user linkages exist within any industry sector—even aerospace where such connections are a near universal characteristic; British industrial management tends to be hierarchical and better suited to small enterprises; and virtually no coordination between banks and industrial enterprises exists.

Fourth, British investment in R&D has been consistently unimpressive. Public expenditures on R&D in the U.K., though relatively high throughout most of the post-war period, were not very effective, and they have declined dramatically since the 1970s; in addition, spending on basic research has been relatively low. With most of the funding focused on defense, little was left to support commercial developments. As public funds vanished, the private sector was expected to step up to the plate. British policymakers—influenced by a neo-liberal ideology which advocates that industry alone should decide which technologies to bring to market and should carry the associated risks as well—have emphasized the need for greater "value-for-money"; in doing so, they have "diverted attention away from the large-scale, collective, and resource-intensive nature of much contemporary technological activity," and failed to recognize the risk-averse nature of firms when faced with lengthy and uncertain return-on-investment cycles (Walker, 1993, p. 186). (For more on the characteristics of Britain's innovation system, see Cairncross, 1992; Chandler and Daems, 1980; Desai, 1989; Freeman, 1989; Hayward, 1989; 1983; Jones, 1985; Young and Hood, 1984).

Following World War II, British policymakers perceived a need for greater public involvement in technological innovation. Direct R&D funding, laboratories and other research facilities, public procurement intended to create new production capabilities and spawn new or re-create older industries—in particular nuclear and aerospace—were all adopted as parts of a transparent industrial policy. Research associations designed to pool corporate resources were encouraged with matching public funds. During the 1960s, the National Economic Development Council (NEDC), a creature of the Labour Party, served as a forum for labor, corporations, and government to develop science and technology strategies. By the 1970s, policymakers were disillusioned by the ineffectiveness and often damaging effects of British government programmatic intervention in the market. Though fluctuating between Conservative and Labour Party governance, public policy began to shift back to its more traditional *laissez-faire* approach to the economy.

By the 1980s, the transition was complete. Margaret Thatcher was in power; state-owned enterprises were privatized; the government sought to reduce public expenditure in general and R&D expenses in particular by passing off both costs and benefits of risky investments to the private sector. Budgetary allocations were centralized within the Cabinet Office; its Advisory Committee on Science and Technology (ACOST) became the focal point for S&T conversations, with an emphasis on competition, entrepreneurship, and decentralized decision-making. The only exceptions to these trends were continued commitments to defense R&D and to Airbus Industrie-related launch aid. Local Enterprise Agencies and science parks—products of

joint ventures by government, business, financial institutions, and universities—appeared; starved for capital, these entities have mostly sought to make themselves attractive to foreign investment.

By the mid-1990s, the U.K. had fallen behind its European neighbors in terms of public support for aeronautical research and technology acquisition (R&TA). Even R&TA funded through the defense budget has declined, reflecting both general trends in defense spending and changes in procurement philosophy. Corporate contributions to defense research and demonstrator programs have risen from a typical 15% in the late 1980s to at least 35% in 1993; in some cases, programs, once funded completely by the Ministry of Defence (MoD), now receive private support of roughly 30-40% (House of Commons, 1993). As the government distances itself from industry support, Britain is becoming increasingly integrated into the European innovation system. For all intents and purposes, the U.K. has ceded its leadership in aeronautics and commercial aviation to France and is dependent on foreign investment to finance technological development (Adkins, 1993; Hayward, 1994; Patel and Pavitt, 1990; U.K. House of Commons, 1993; U.K. Parliament, 1965; U.S. International Trade Commission, 1993; Walker, 1993).

The Evolution of British Innovation Public Policies in Aviation

Britain's commercial aviation development following World War II reflects its ambivalence about the proper role for government in the market; "responsibility for project choice, monitoring and control was left in limbo between a full, free-market private-enterprise system and state interventionism" (Hayward, 1983, p. 36). The British were among the first to recognize aviation's potential strategic value; they rejected a freedom-of-the-air doctrine proposed at a 1910 international law conference which was grounded in Hugo Grotius' 1604 freedom-of-the-seas principle. They favored recognition of sovereign air space above national territories and acted decisively to safeguard theirs by empowering the state "to regulate the entry of foreign aircraft and to proscribe zones over which foreign aircraft were not allowed to fly" (Jönsson, 1981, p. 271). The European continent quickly followed suit (Cooper, 1947; 1952; Golich, 1989; Jönsson, 1981).

As British aviation transitioned from small, competitive, engineer-entrepreneurs to big business, the government supported the industry via procurement from a "magic circle" of manufacturers; the intent was to sustain a "strategic reserve" of private firms by guaranteeing a constant flow of income from state-owned airlines which were required to "Buy British"-manufactured aircraft (Hayward, 1983, p. 4). During World War II, the government established an aviation review committee, chaired by Lord Brabazon, to develop and implement a plan to exploit the British advantage deriving from their discovery and development—concurrently with, but obviously separately from, the Germans—of jet-engine technology. Despite a bias against detailed government involvement in the market, the committee literally designed nine transports, known as the "Brabazon Types," and then required British aircraft manufacturers to build them. The option of pursuing licensed production with U.S. manufacturers—preferred by most industry managers—was consistently rejected by government policymakers (Golich, 1991; Hayward, 1983; 1989).

Following the war, four factors continued to influence U.K. public policy toward aviation:

> (1) the persistent belief that civil aviation was critical to both national security and economic recovery; (2) a sense of inferiority vis-à-vis the United States related to

> Britain's heavy economic indebtedness to its Atlantic Ally, coupled with the conviction that a revitalized commercial aircraft industry could represent a resurgent and autonomous Britain, less dependent on its former colony; (3) a large aerospace labor pool; and (4) the postwar Labour government's ideological commitment to a planned, centrally directed industrial and economic recovery (Golich, 1991, p. 129).

Unfortunately for Britain's LCA manufacturers, this period of government involvement was ineffective at best and harmful at worst. Insensitive to the complex nature of market forces, public policymakers defined specific product outcomes rather than supporting general technology advances. British airlines were caught in the middle: They were required to "Buy British" as an "honorable legacy of the war" (Hayward, 1983, p. 15), but doing so meant they were unable to compete in the global market—where most of the traffic could be found—because passengers sought the better quality service provided by other (mostly U.S.-manufactured) LCA. A series of governmental inquiries led to a variety of imposed changes in the way business was conducted in the industry—ranging from forced collaboration between airlines and aircraft manufacturers, to revised versions of "Buy British," to excessive reliance on parochially-influenced, airline-determined specifications—but none were successful. The rocky road from little or no, to excessive, to ineffective, full circle to little or no government involvement that bedeviled technology innovation strategies and policies in general, also plagued policies directed at aviation. (For more on the mercurial relationship between government and industry in aviation, see Cooper, 1947; 1952; Desai, 1989; Golich, 1989; 1991; Hart, 1986b; Hayward, 1983; 1989; Hochmuth, 1974; Jones, 1985; Jönsson, 1981; Shepherd, Duchene and Saunders, 1983; Walker, 1993; Young and Hood, 1984).

Current Structure of British Aeronautical Knowledge Diffusion

Three agencies support aeronautical R&D in the United Kingdom: the Ministry of Defence, the Department of Trade and Industry (DTI), and the Department of Transportation (DoT). In addition government agencies fund more general R&D—not necessarily aeronautical—in universities and research establishments. The U.K.'s DoT funds R&D activities intended to solve problems related to the public interest, such as aircraft safety, noise and environmental pollution, and aviation security.

The MoD is the U.K.'s primary sponsor of public aerospace R&D—including aeronautical research—for both civil and military use. The Royal Aerospace Establishment—the Aerospace Division of the MoD's Defence Research Agency—conducts most of Britain's aeronautical research. Funded by MoD contracts and by private industry revenues, the DRA operates in a commercial fashion and does not receive institutional support from the British government. Because the DRA competes with industry for DTI aeronautical research contracts, a potential conflict of interest arises with respect to sharing data with firms. The extent of direct technology transfer into the public domain depends upon the terms of individual contracts. The contract mechanism is seen as a means of increasing the efficiency of DRA operations, but it has given rise to fears that the DRA will neglect long term research (U.S. Congress, General Accounting Office, 1994). Although the DRA has introduced procedures designed to speed up transferability of defense technology into the civil sector—and there are few institutional barriers between defense and civil aerospace activity at the level of the firm—British companies regularly complain that data do not reach private industry fast enough and several U.K. corporate officials have argued that the MoD should let more of its contracts directly with industry (U.S. Congress, General Accounting Office, 1994; U.K. House of Commons, 1993).

The DTI provides launch aid for civil aeronautics programs guided by two key principles: *First*, up to 60% of non-recurring R&D costs may be financed; however, aid or guarantees for production is seldom provided. In theory, all aid—plus interest—must be repaid from levies on sales; nonetheless, few programs have fully repaid their launch aid, though receipts from royalties have outpaced grants for the last three years. *Second*, to receive aid, a project must be demonstrably viable in commercial and technical terms, but risky enough that a company would not otherwise pursue the project. In theory, launch aid is available for equipment firms, but none have received any since the 1950s (Hayward, 1983). All of BAe's major Airbus projects since 1978—A320, A330, A340—have received launch aid, as has RR's investment in the RD&P of the RB211 engine family, whereas neither RR's Trent high-power engine nor BAe's R&D of a new range of regional jet airliners has.

DTI also funds civil technology R&D and research facilities to enhance the British aeronautical technology base through its Civil Aircraft Research and Demonstration (CARAD) program, which focuses on long term, pre-competitive research for airframes, propulsion, and avionics (U.K. House of Commons, 1993; U.S. Congress, General Accounting Office, 1994; U.S. Congress, Office of Technology Assessment, 1991; U.S. International Trade Commission, 1993). DTI's CARAD budget declined dramatically over the last ten years prompting the development of a National Strategic Technology Acquisition Plan (NSTAP). Published in 1993, the final report identified three categories of research which should inform government and industry R&TA activity over a 10-15 year span, including

- technologies fundamental to the future well-being of U.K. industries from which the critical competitive edge will emerge—the "crown jewels" technologies which provide an independent capability or an influential role in global ventures;
- enhancing technologies which will improve the effectiveness of U.K. industry, and without which the potential of U.K. firms will be damaged; and
- supporting technologies mainly imported from other industries without which the U.K. will be severely disadvantaged in the long term (U.K. House of Commons, 1993).

NSTAP also recommended ways of improving the efficiency of U.K. R&TA spending. In particular, British R&TA had to be placed within a clearly defined national strategy for the aerospace industry and to identify how Britain could make the best use of international, especially European programs. Finally, NSTAP urged the adoption of a number of technology demonstrator programs that could act as a focus and catalyst for near-market research (House of Commons, 1993).

The NSTAP exercise helped to inform British approaches to technology planning generally. In an echo of the Japanese, MITI-led "visions" (see Pinelli, Kennedy, Barclay, and Bishop, 1997, Chapter 18), the U.K. has launched a "Foresight" exercise to help identify key technologies for the next two decades. "Defence and Aerospace" comprises one of the Foresight panels. Over a period of several months during 1994, the Foresight panels gathered evidence from industrialists, officials and academics on opinions and insights about aerospace technology and market needs up to 2015. The results will be used to guide budgetary planning for government and industry R&D.

Despite this flush of "strategic-thinking," British industry still faces a net decline in public funding for civil aerospace R&TA over the next few years. Moreover, the DRA may now be more market-driven than is good for the health of the U.K. aerospace industry. The potential problem is magnified by the potential "squeeze out" effect of "mission-oriented" commitments to defense and to aerospace (Walker, 1993). In this respect, a decline in public spending in these areas, with an accompanying shift of resources to "diffusion-oriented" strategies might be welcome. However, given that defense and civil aeronautics constitutes one of the few areas of world class British manufacturing, the resultant transition costs could be high. Worse still, the current U.K. government is reluctant to make the necessary commitments to a training and research infrastructure which would be needed to implement an effective diffusionist strategy.

CONCLUSIONS

Despite the order of magnitude change in our daily lives wrought by innovation rooted in knowledge and technological discovery, little has changed in the underlying concepts which guide government policy-makers in their interactions with other nations. Indeed, "the policy processes dealing with science and technology and the enterprises that encompass them remain predominately national, even if progress in science and technology and in their applications inexorably moves toward international and even global effects" (Skolnikoff, 1993, p. 27). Government policies influence the nature of technology that emerges within national boundaries; moreover, public policies are still intended to serve the objectives of the state, whether focused on military, economic, political, social security, or some combination of purposes.

Public policies and strategies which target knowledge diffusion are the product of national history, culture, and perceived needs. Hence, they influence the nature of technological change. Thus, it is critical to reflect on the match between articulated governmental goals and the policies and strategies used to achieve them. For example, no approach to knowledge diffusion is without its faults. A mission orientation tends to be too focused on a single goal—usually national defense—which may or may not have value for the broader economy. Such an approach is more susceptible to the problems associated with "picking winners and losers." There is less room for the market to evaluate targeted projects because the government has mandated that the project be pursued, has sunk significant resources into ensuring it is sought, and is, therefore, reluctant to change course. Usually, by the time a project is determined to be a loser, the cost in every sense—financial and human capital, social welfare, economic externalities—is significant. Occasionally, as in the case of the Concorde, market failure and the associated financial costs are somewhat compensated for by the derivative benefits of learning to manage a transnational project of immense complexity and sophistication (Hayward, 1994; 1993; 1986). More frequently, government involvement pulls decision-making away from program and project managers, creates a rigid hierarchy, fosters competition rather than cooperation, and leads to antagonistic relationships between labor and management. Despite these problems, the French, British, and U.S. experiences have demonstrated that a mission orientation can yield significant successes. Airbus and the constellation of French aerospace firms—including *Aérospatiale*, Dassault, SNECMA, and Thomson-CSF, Dassault Electronics, and Sextant Avionics—and British firms—BAe, Rolls-Royce, and several key component suppliers—have delivered impressive products which have enjoyed significant market success. Boeing's success is clearly evidenced by its overwhelming and persistent domination of the LCA market.

A diffusion approach does not allow for as much control or direction by the government as a mission-oriented approach. Because a diffusion orientation is not tied to a specific, measurable outcome—e.g., a family of new generation LCA—it is difficult to assess its success. A diffusionist approach requires significant up-front and on-going public investment in research, testing, and production facilities; in educational, training, and research institutions; in a research and technology infrastructure replete with incentives for collaboration among industry, academic, and government research facilities; and in financing technology developments. Much like LCA RD&P, a diffusionist approach is risky business; it is expensive and carries uncertain and distant payoffs. Nevertheless, the benefits of such an approach to knowledge and technology diffusion seem to outweigh its costs. Because it facilitates communication and coordination among researchers, it has a greater potential for eliminating potentially costly duplication of effort while encouraging the kind of cross-disciplinary intellectual stimulation that can lead to dramatic knowledge and technology discoveries.

What is clear is that government intervention in support of knowledge diffusion is a pervasive characteristic of the twentieth century (Lazonick, 1991). No single approach will work for all countries. The range of options for government intervention in the market is significant when one considers the mission-diffusion, direct-indirect, opaque-transparent overlapping continua. Whatever approach is adopted, policymakers are well-advised to be clear and open about why and how they plan to implement it. Such open discourse enables policymakers to negotiate difference and manage potential conflict.

Even though no single prescription will fit all national or industry sector needs, it does seem safe to conclude that new technologies, enhanced organizational capabilities, and more efficient production processes—such as those brought to LCA RD&P by Airbus Industrie in Europe and by Boeing in the U.S. (see Pinelli, Kennedy, Barclay, and Bishop, 1997, Chapters 1 and 2)—are critical to the creation of valuable goods, processes, and services for the market. Whereas "public authorities can help firms respond to these pressures by providing a technological infrastructure to facilitate innovation by individual producers," (Majumdar, 1987, p. 515), such efforts must transcend sector-specific public policies. Under conditions of global oligopoly resulting from large economies of scale and barriers to entry,

> the more dominant the existing organizations and the greater the capital investments required to enter the global industry, the more necessary will it be for a national strategy to give privileged access to public resources to those national business organizations that can best develop and utilize these resources. (Lazonick, 1991, p. 88)

Even if countries are more open about their intervention to promote knowledge diffusion, we are still confronted with the tension between national advancement and the market forces in high-cost, high-technology industries impelling us toward globalized RD&P. After all, for much of recorded history, competition has been one of the most important forces driving scientific research and technological development. Rivalry between nation-states has been particularly important in this regard. Many significant developments in transportation and navigation, communications, and especially weaponry originally grew out of the efforts of one country to gain some military or economic advantage over its neighbors (or to prevent its neighbor from gaining such an advantage).

A global RD&P structure, much like transnational strategic alliances among firms, requires a certain level of trust and communication among participants which speaks against the kind of free riding which is implicit in seeking collaboration for the purposes of national advancement (Lorell, 1980). The past two decades have witnessed a dramatic shift toward collaboration, particularly during the research and development (R&D) phases of critical projects. The rise of the "global economy," the "transborder reach" of many new technologies, the rapidly growing costs associated with a number of R&D activities, the end of the Cold War which eased concerns about the vulnerability potentially associated with transnational collaboration appear to weigh more heavily now than the old competitive forces still in place. The rise of transnational R&D collaborative projects represents a change of historic magnitude, and every indication suggests it is a trend that will continue well into the twenty-first century (Golich and Kay, 1997).

This transformation is not without significant irony. For example, following World War II, European governments sought to dominate civil aviation unilaterally because of its perceived strategic value; they pursued that goal with heavy state involvement. Eventually, market forces propelled a variety of transnational joint ventures among firms as well as a pooling of scarce research, human, and financial capital in governmental research agencies.

Another irony emerges as private-sector cooperation begins to achieve success. To facilitate further private-sector growth by making transnational ventures even more efficient and effective, state officials must coordinate government functions such as harmonizing standards for the safe and competent operation of a commercial aviation production and transportation system (see Pinelli, Kennedy, Barclay, and Bishop, 1997, Chapter 2). This can lead to the creation of supranational governmental authorities, such as the Joint Airworthiness Requirements Authority. Eventually the network of private and public activity becomes so complex and intertwined that the beginnings of a new political organization emerges. In any case, for the foreseeable future, one of the primary challenges confronting government and corporate decision makers is how to negotiate the tenacious tension between national priorities and global imperatives.

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